High Resolution Climate Data From Research and Volunteer Observing Ships

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1. PROJECT SUMMARY

This project involves the measurement of direct high-resolution air-sea fluxes on one to two cruises per year and the development of a roving standard flux measuring system to be deployed on a series of NOAA and UNOLS research vessels to promote the improvement of climate-quality data from those platforms. An adjunct task is maintenance and operation of the C-band scanning Doppler radar and the stabilized wind profiling radar on the NOAA ship *Ronald H. Brown*. Because buoys and most ships and satellites rely on bulk methods to estimate fluxes, another aspect of this project is the use of direct measurements to improve the NOAA/COARE bulk flux algorithm. Originally one cruise was the annual TAO buoy tending cruise to 95 and 110 W on the *Ronald Brown*, but that has been discontinued in favor of an annual cruise to the equatorial Atlantic Ocean with Dr. Bob Molinari (AOML) as part of the African Multidisciplinary Monsoon Analyses (AMMA) and Saharan Dust studies. The second cruise, which also occurs in the fall, is the annual excursion to turn around the Stratus climate buoy at 20 S 85 W. A full suite of direct, inertial-dissipation, and bulk turbulent fluxes are measured along with IR and solar radiative fluxes, precipitation, and associated bulk meteorological properties. This effort represents a partial transition of research from the OGP CLIVAR PACS program to operations under the Climate Observations Program (COP).

The project development is the result of a recent NOAA-sponsored workshop on high-resolution marine measurements (Smith et al., 2003, *Report and Recommendations from the Workshop on High-Resolution Marine Meteorology*, COAPS Report 03-01, Florida State University, pp38) which identified three important issues with the planned NOAA air-sea observation system: 1) the need for a data quality assurance program to firmly establish that the observations meet the accuracy requirements, 2) the need for observations at high time resolution (about 1 minute), 3) and the need to more efficiently utilize research vessels, including realizing their potential for the highest quality data and their potential to provide more direct and comprehensive observations. For seasonal time scales, the net air-sea flux (sum of 5 flux components) must be constrained within 10 Wm^{-2}. Buoys and VOS systems are required to operate virtually unattended for months, so considerations of practical issues (e.g., power availability, instrument ruggedness, or safe access) are balanced against inherent sensor accuracy and optimal sensor placement. As discussed above, an important function of the in situ measurements is to provide validation data to improve NWP and satellite flux fields. Here, high time resolution and more direct observations are invaluable for interpreting surface flux measurements and diagnosing the source of disagreements; such information can be provided by suitably equipped research vessels (R/V). Thus, the accuracy of buoy and VOS observations must be improved and supplemented with high-quality, high time resolution measurements from the US R/V fleet (which is presently underutilized). The necessity for both high time resolution and high accuracy places extreme demands on measurements because some sources of error (such as the effect of ship flow distortion on wind speed) tend to average out over a large sample. To accomplish this task will require a careful intercomparison program to provide traceability of buoy, VOS, and RV accuracy to a set of standards.

This project directly addresses the need for accurate measures of air-sea exchange (Sections 5.2 to 5.4, *Program Plan for Building a Sustained Ocean Observing System for Climate*. The project is a joint effort by ESRL and Dr. Robert Weller of the Woods Hole Oceanographic Institution (WHOI). NOAA COP funds the ESRL component and Dr. Weller is seeking NSF fund for the WHOI component. The ESRL Air-Sea Interaction Group website can be found at: http://www.etl.noaa.gov/et6/air-sea/. ESRL also cooperates with Dr. Andy Jessup (APL University of Washington) on radiative sea surface temperature measurements, Dr. Frank Bradley (CSIRO, Canberra Australia) on precipitation, Drs. M. Cronin and N. Bond (PMEL) on buoy-ship intercomparisons and climate variability analysis, and Dr. Mike Reynolds (DOE BNL) on radiative fluxes. A new website is under construction for this project (High Resolution Climate Observations http://www.esrl.noaa.gov/psd/psd3/air-sea/oceanobs/). An associated website (http://www.esrl.noaa.gov/psd/psd3/wgsf/) contains a handbook on best practices for flux measurements plus a database of high-resolution flux data. This work will be closely monitored by the WCRP Working Group on Surface Fluxes (WGSF) which is chaired by C. Fairall. This will give the project high visibility in the CLIVAR, GEWEX, and SOLAS programs. This project will be managed in cooperation with JCOMM (and other) panels as per instructions of Mike Johnson.

2. ACCOMPLISHMENTS

For the *Ronald Brown* C-band and wind profiler radar project, major maintenance was performed in August 2008 in Charleston, SC, right before the NOAA CPPA VOCALS cruise planned October-November 2008.

ESRL completed three research cruises. The preliminary raw and processed data from these three cruises can be found at ftp://ftp.etl.noaa.gov/et6/cruises.

*The Bob Molinari buoy deployment cruise in the Atlantic in the spring of 2008 (this is the *PNE/AMMA-Saharan Dust* cruise) on board the R/V *Ronald H. Brown*. This cruise was essentially cancelled because of problems with the *Brown* but we manned the cruise and took data on the Uruguay to Charleston transit.

*The NOAA IPY ICEALOT cruise on the R/V *Knorr* (http://saga.pmel.noaa.gov/Field/icealot/). The portable flux standard was installed on the *Knorr* in Woods Hole, MA. The cruise was from Woods Hole, to Tromso, Norway, and back to Iceland. The principal goal of the cruise was to study aerosol-cloud interactions in the Arctic. We also used the cruise for the first intercomparison of the flux standard with a UNOLS ship.

*The joint ESRL/WHOI cruise to the climate reference buoy (25 S 80 W) on board the *Brown* in October 2007. Our role in this cruise is to provide standard observations for the WHOI flux reference buoy and to quality check the R/V *Brown* sensors. We worked with Bob Weller to perform a fairly comprehensive check of radiative flux measurements from the deck of the *Brown*. This included ESRL and WHOI Eppley radiative sensors, the Brown IMET sensors, and a new set of Kipp & Zonen (K&Z) sensors. We also operated the newly developed ESRL pitch-roll stabilized platform with K&Z sensors mounted on it. This comparison has uncovered a bias difference of about 3% between the Eppley and K&Z sensors (see Figure 1). This represents a possible error of 5-10 W/m^2, which exceeds the allowed uncertainty in the surface radiation budget to meet the standards of the flux reference sites. A batch of these sensors was calibrated at the BSRN calibration facility in Boulder over the summer of 2008, but we have not yet resolved the conflict.

ESRL also made two trips to the Coastguard/NSF icebreaker *Healey* to advise on installation and sensors for their new meteorology observations system. We placed sensors on board for a one-week test cruise in January 2008. We worked with the SAMOS group at Florida State University concerning quality control of data from the *Healy*. A preliminary report on this was given at the SAMOS/GOSUD conference in Seattle in June 2008.

In 2007 we produced a synthesis of the main results of the previous five years of strategic observations in the form of three scientific publications. In 2008 we produced a synthesis flux and boundary layer **data set** from the Stratus cruises to the WHOI buoy at 20 S 85 W which is now publically available (http://www.esrl.noaa.gov/psd/psd3/synthesis/). This data set is intended for quality assurance and context for interpreting the buoy observations at this site but the principle reason for this synthesis set is to provide easy to use but very accurate observations for model and ocean data assimilation guidance.

Considerable progress was also made on developing the portable flux standard and implementing ship and buoy intercomparisons for quality assurance. Production of the roving flux standard is now complete. The portable standard was deployed in spring of 2008 (see above).

The PI of this project has been chair the WCRP Working Group on Surface Fluxes (WGSF) since 2003. He also serves on the International Geophysical Union International Climate Dynamics and Meteorology Working Group A (Boundary Layers and Air-Sea Interaction). In 2004 he was invited to join the SOLAS Focus 2 (air-sea flux physics) Working Group to develop the Surface Ocean-Lower Atmosphere Study (SOLAS) International Implementation Plan and has been named to the US SOLAS Advisory Group. In 2008 he joined the CLIVAR High Latitude Flux Working Group (http://www.usclivar.org/hlat.php).

3. PUBLICATIONS

Kara, Birol, Alan J. Wallcraft, E. Joseph Metzger, Harley E. Hurlburt, and C. W. Fairall, 2007: Wind stress drag coefficient over the global ocean. *J. Clim.*, **20**, 5856-5864.
ftp://ftp.etl.noaa.gov/user/cfairall/oceanobs/pubs/fy08/

Fairall, C. W., J. E. Hare, T. Uttal, D. Hazen, Meghan Cronin, Nicholas A. Bond, and Dana Veron, 2008: A seven-cruise sample of clouds, radiation, and surface forcing in the Equatorial Eastern Pacific. *J. Clim*., **21**, 655-673.
ftp://ftp.etl.noaa.gov/user/cfairall/oceanobs/pubs/fy08/

Weller, R.A., E.F. Bradley, J. Edson, C.W. Fairall, I. Brooks, M.J. Yelland, and R.W. Pascal, 2008: Sensors for physical fluxes at the sea surface: Energy, heat, water, and salt. *Ocean Sci. Discuss*., **5**, 327-373.
ftp://ftp.etl.noaa.gov/user/cfairall/oceanobs/pubs/fy08/

Ghate, Virendra P., Bruce A. Albrecht, Christopher W. Fairall and Robert A. Weller, 2008:

Climatology of marine stratocumulus cloud fraction in the South-East Pacific using surface longwave radiative flux observations*.* *J. Clim.*, to appear.

De Szoeke, S.P., C.W. Fairall, and S. Pezoa, 2008: Ship observations coasting South America in the tropical Pacific Ocean. *J. Clim.*, to appear.

4. CONFERENCES

29^{h} Session of the Joint Scientific Committee for the WCRP, World Climate Research Program, Arcachon, France, 31 March–4 April 2008. Presentation: The WCRP Working Group on Surface Fluxes. (http://wcrp.wmo.int/documents/JSC29FinalReport.pdf)

Symposium on Observing the Turbulent Atmosphere: Sampling Strategies, Technology, and Applications. NCAR, 28-30 May 2008, Boulder, CO. Invited talk: *Turbulence measurements for surface-layer micrometeorological studies over sea and sea ice.*

2nd Joint GOSUD/SAMOS Workshop, Seattle, Washington, USA, 10 - 12 June 2008. *Shipboard Meteorological Measurements: Interpretation and Quality Assessments.*

Office of Climate Observation 5^{th} Annual System Review, NOAA, Silver Spring MD, 2-5 September 2008. Poster presented: *The ESRL Portable Seagoing Flux Standard: Preliminary Quality Assessments from Healy and Knorr.*

WCRP WOAP-III meeting, Boulder, CO, 29 Sep.-1 Oct. 2008. Talk presented: *Report on the Working Group on Surface Fluxes: Present Status and Future Plans.*

5. FIGURES

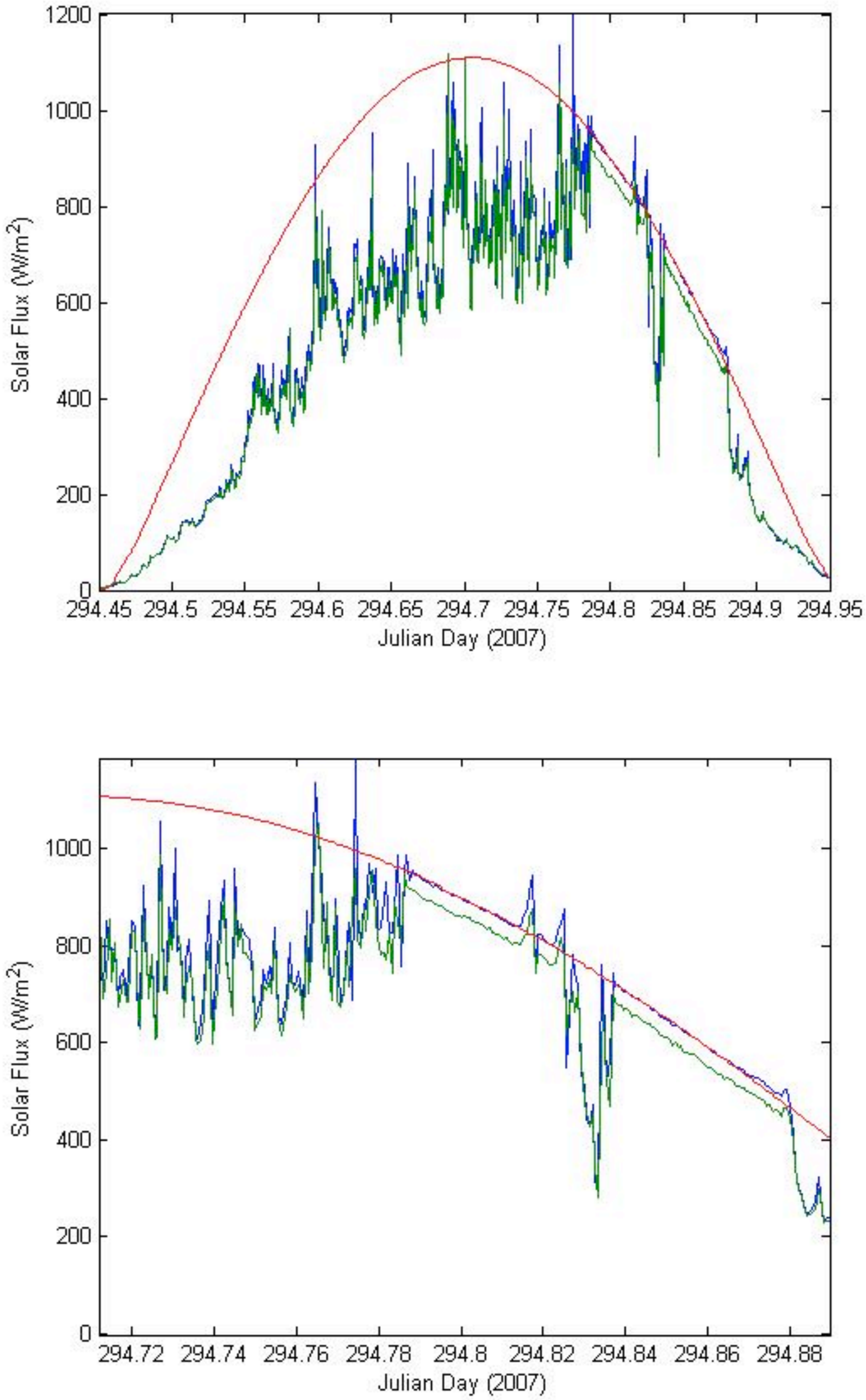

Figure 1. Solar flux vs time at 1-min resolution on from the WHOI flux reference site at 20 S 85 W Julian Day 294: red line – clear sky flux model; blue line – mean of two K&Z sensors; green line - mean of five Eppley sensors. The lower panel is a detail from JD 294.71 to JD 294.89 (4.3 hrs). Clear periods are indicated by very smooth traces of the time series and values near the clear-sky flux model (e.g., between 294.78 and 294.82). Note the green line is about 3% lower than the blue line.